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Effect of 18-h watch schedules on circadian cycles of physiological functions during submarine patrols

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Schaefer, K. E., C. M. Kerr, D. Buss, and E. Haus. 1979. Effect of 18-h watch schedules on circadian cycles of physiological functions during submarine patrols. Undersea Biomed. Res. Sub. Suppl.: S81–S90.—Circadian rhythms of body temperatures, pulse rate, and respiration rate were measured in 11 subjects every 4 h during certain periods on two submarine patrols. Data on systolic and diastolic blood pressure were also obtained on five crew members during the first period. All the subjects of the first patrol were on an 18-h watch schedule (6 h on, 12 h off). During the second patrol, three subjects were on an 18-h watch schedule and three were on a 24-h watch schedule. Cosinor analysis for positive ($P<0.05$) detection of rhythm demonstrated that all subjects on the 18-h watch schedule developed 18-h cycles of body temperature, pulse rate, respiration rate, and systolic and diastolic blood pressure, which were then superimposed on the persisting 24-h cycles of the same function. The three subjects on a 24-h watch schedule did not show the 18-h cycles. Moreover, additional 12-, 36-, and 48-h cycles (harmonics and subharmonics of 24-h cycles) were found in all subjects on both patrols, attesting to the disintegration of circadian cycles under these conditions. Average sleep time tended to decrease toward the end of the patrol.

circadian cycles
submarine patrols
18-h watch schedules
sleep

Operational schedules on a deployed submarine consist of watchstanding routines which disrupt the normal 24-h daily regimen. For nuclear-powered submarines (SSBN), the most frequent watch schedule is 6 h on duty, followed by 12 h off duty. This schedule is superimposed on the 24-h meal and social schedules, which act as 24-h environmental "time givers" (*Zeitgebers*).

In a recent paper on circadian rhythms in body temperature during prolonged sea voyages, Colquohoun, Paine, and Fort (1978) described in watchstanders (4-h watches) a "disintegration of the 24-h body temperature rhythm into shorter periods, notably 4 and 8 h," and decrease in the amplitude of the circadian cycle. To avoid the breaking up of the 24-h circadian rhythms and its possible effects on efficiency, these authors recommended an 8-h on, 16 h-off system, as did Kleitman (1949) nearly 30 years ago.

Russian studies have demonstrated that among a variety of work-rest schedules tested, the 18-h cycle was the most detrimental, as indicated by an evaluation of neural and muscular functions (Andrezsyuk 1968). Other Russian investigations have shown that 18-h work-rest cycles result in somnolence, restlessness, and emotional disturbance with impaired coordination (Dushkov and Komolhinskii 1968). This paper will report results of the effects of an 18-h watch schedule on the circadian rhythm of body temperature, pulse rate, and respiration rate in 11 submariners on patrol.

MATERIALS AND METHODS

During the first patrol, measurements of oral temperature, pulse rate, respiration rate, and systolic and diastolic blood pressure were carried out by a medical officer and corpsman every 4 h on five subjects during 5 days of the refit period before the patrol, for the first two weeks of patrol, and during 12 days toward the end of the patrol. All subjects were on an 18-h watch schedule.

With the exception of diastolic and systolic blood pressure determinations, essentially the same measurements were made on six subjects during the second patrol; however, no control data were obtained in the second patrol study. During the second patrol, three subjects were on an 18-h watch schedule while three other subjects had a regular 24-h schedule.

By using a special purpose computer program, the data were statistically analyzed by fitting the cosine function over a frequency range between 10–48 h by the least squares method (Halberg, Tong, and Johnson 1967). This so-called cosinor analytical approach makes it possible to determine the presence or absence of rhythms with periodicities of 24 or 18 h, or other durations. Rhythm detection was accepted at a P value of $P<0.05$. Phase relationships, rhythm-adjusted means (mesor) and amplitudes of the rhythms were also determined with these procedures.

RESULTS

Figure 1 presents the frequency distribution of rhythms detected by cosinor analyses ($P<0.05$) in five subjects during the first patrol. Control data could only be obtained during a 5-day sampling span, which occurred in the rather stressful refit period before the beginning of the patrol. During the control period, incidence of significant rhythm detection was rather low and was limited to 24-h rhythms. The number of rhythms in the circadian range (21–24 h) increased during the first 14 patrol days. However, 18- and 12-h cycles also appeared and their incidence continued to rise toward the end of the patrol (41–52 days). The subjects under investigation were rather dissimilar in respect to their circadian cycles, as shown by the limited number of statistically significant 24-h cycles.

During the refit period, the circadian cycle was statistically verified and quantitatively established for the whole group for pulse rate only. During the first part of the patrol (1–15 days), cosinor analysis showed statistically significant rhythms for respiratory rate and for the ratio of heart rate/respiratory rate. During the later part of the patrol (41–52 days), the group did not exhibit a detectable circadian rhythm in any of the functions. Table 1 lists means and SEs of the various functions measured during the patrol for the total group of subjects. Body

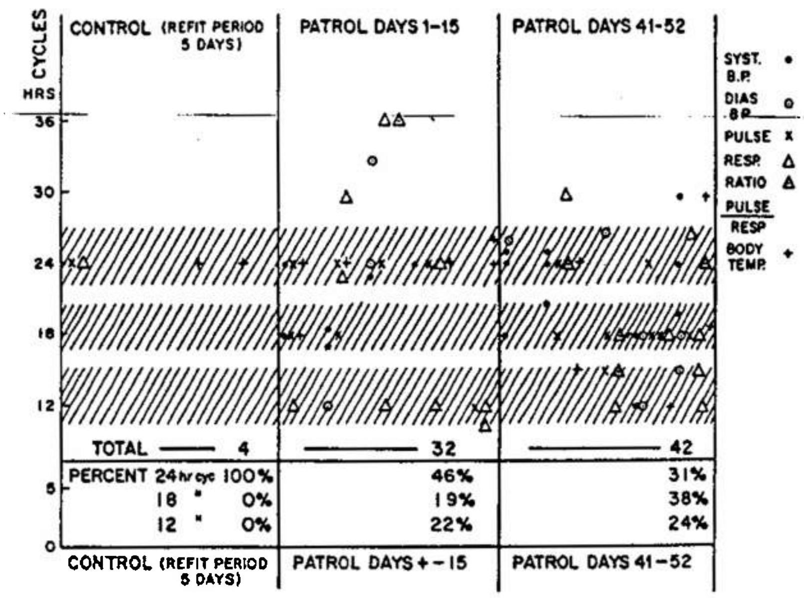

Fig. 1. Effect of 18-h watch schedule on frequency distribution of rhythms (5 subjects). Cosinor analysis was carried out on rhythms of individual subjects.

temperature, pulse rate, and respiration rate showed a tendency to decrease during patrol (Table 1). Acrophase of body temperature and pulse rate exhibited a trend to shift ahead.

In the second patrol, the effects of two different watch schedules were studied simultaneously. An example of the data obtained on one subject on an 18-h watch schedule (6 h on, 12 h off) is shown in Fig. 2. Sleep-wakefulness periods and cycles of body temperature, respiratory rate, pulse rate, and ratio of pulse rate to respiratory rate are plotted for the three periods during which data were collected. Body temperature, respiration rate, and pulse rate exhibit cycles longer than 24 h (36–40 h range) on Day 8 and Day 10, as indicated by arrows in Fig. 2. These 36–40 h cycles became even more pronounced in the third period on patrol during Day 33 and Day 34, where they appeared simultaneously in body temperature, respiration rate, and pulse rate.

Since the number of subjects in each of the two groups was too small for a group cosinor analysis, data on mean values and amplitudes of the function studies were calculated and are presented in Table 2. Subjects on an 18-h watch schedule showed trends toward an increase in pulse rate and a decrease in respiratory frequency. These changes were reflected in an increase in the pulse rate/respiratory rate ratio. Moreover, a transient marked increase in pulse rate was observed during the 6th week of patrol. A trend toward a decrease occurred in all functions studied in this group during the later periods on patrol. None of these trends was observed in subjects on the 24-h watch schedule.

The influence of two different watch schedules (18 h and 24 h) on the frequency distribution of rhythms in body temperature, pulse rate, respiratory rate, and ratio of pulse rate/respiratory rate is shown in Table 3. Subjects on an 18-h watch schedule demonstrated increased frequency of occurrence of 18-h cycles, from 15% during the first week to 30% during weeks 4, 6, and 7, while the percentage of 24-h rhythms declined from 46% during the first week to 30% at the seventh week for the same subjects.

TABLE 1
CIRCADIAN CYCLES OF PHYSIOLOGICAL FUNCTIONS DURING PATROL

Experimental Condition	Variance	Rhythm Detection, *P*	Mesor, M ± SE	Amplitude, 95% PCT/CL	Acrophase, h
Control	Body Temperature (Oral)	>0.05	35.74±0.16	0.25	1920
Refit Period	Pulse Rate	<0.05	73.5 ±6.15	4.44±4.39	2000 (1440–2400)
(5 Days)	Respiratory Rate (RR)	>0.05	16.4 ±2.89	0.95	2040
	Pulse-RR Ratio	>0.05	4.67±0.81	0.06	1400
	Systolic Blood Pressure	>0.05	116.08±3.46	1.47	1840
	Diastolic Blood Pressure	>0.05	75.07±6.22	0.89	2000
Patrol	Body Temperature (Oral)	>0.05	35.66±0.50	0.11	2315
1–15 Days	Pulse Rate	>0.05	70.02±8.11	3.07	2000
	Respiratory Rate (RR)	<0.05	15.30±1.68	0.78±0.50	1840 (1540–0120)
	Pulse-RR Ratio	<0.05	4.69±0.68	0.15±0.12	0400 (2000–0640)
	Systolic Blood Pressure	>0.05	116.13±6.37	3.62	1820
	Diastolic Blood Pressure	>0.05	73.32±5.76	1.02	1720
Patrol	Body Temperature (Oral)	>0.05	35.69±0.40	0.09	2300
41–52 Days	Pulse Rate	>0.05	73.00±8.93	3.78	2200
	Respiratory Rate (RR)	>0.05	14.98±1.72	0.48	2300
	Pulse-RR Ratio	>0.05	4.93±0.41	0.10	2000
	Systolic Blood Pressure	>0.05	116.12±4.96	3.55	2200
	Diastolic Blood Pressure	>0.05	72.55±2.55	1.05	1920

Analysis based on cosine curve fitting: mesor, M = 24-h rhythm-adjusted mean. Amplitude A = difference between M and value measured at acrophase. Acrophase ϕ = peak of best-fitting sine curve, to approximate the rhythm.

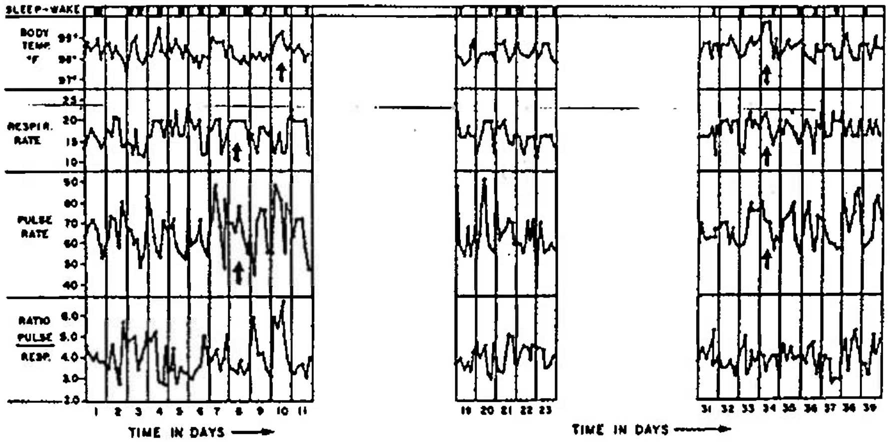

Fig. 2. Sleep-wakefulness period and cycles of body temperature, respiratory rate, pulse rate, and ratio of pulse rate to respiratory rate in a subject on an 18-h watch schedule during a submarine patrol; arrows mark appearance of 36–40 h cycles.

The three subjects on a 24-h watch schedule maintained a rather low level of 24-h cycles during the first week on patrol (38%). However, the frequency of detected 24-h cycles increased subsequently to 80% (week 6) and 61% (week 7). The incidence of 18-h cycles remained low in this group throughout the patrol, varying between 5 and 11%.

During the first two weeks of the patrol, cycles of 36 and 48 h length appeared frequently, particularly in the subjects maintaining a 24-h watch schedule. In the total number of cycles detected during these two weeks, these two frequencies alone accounted for 54 and 48%, respectively. On the other hand, the incidence of 12-h rhythms varied between 5.5 and 20% and did not exhibit any specific pattern in time.

To determine whether there was a tendency to establish free running cycles during submarine patrols, the number of statistically significant cycles in the range of 25–28 h is listed in Table 4 for the different periods of the two patrols. An examination of these data (Table 3) shows a correlation between the number of these cycles and the duration of the patrols.

Possible changes in sleep duration were also studied as the patrols progressed. Accordingly, data on average sleep times were collected on the second patrol. These averages were calculated for a 3-day period to be comparable to data recently published by Colquohoun et al. (1978). During the first 2 weeks of patrol, the sleep time of six subjects averaged 19.6 ± 6 h in a 3-day period. There was a slight tendency towards a decline in sleep duration, as suggested by the sleep time after 4 and 6–7 weeks' patrol, which amounted to 19.2 ± 0.5 and 17.2 ± 0.5 h per 3-day period, respectively.

DISCUSSION

The findings from two patrols indicate that the body responds to two environmental time givers—the 24-h social and meal timing schedule and the 18-h watch schedule—by continuing with 24-h cycles and developing 18-h cycles of physiological functions. Moreover, additional 12-, 36-, and 48-h cycles were detected during both patrols. Cycles of 12-h lengths are submultiples or harmonics of the 24-h rhythm and are known to occur when the time organism is disturbed by factors such as disease (Menzel 1962), stress (Hildebrandt 1960), or disruption of normal life style (Schaefer, Clegg, Carey, Dougherty, and Weybrew 1967).

TABLE 2
MEAN VALUES AND AMPLITUDES OF BODY TEMPERATURE, PULSE RATE, RESPIRATORY RATE, AND PULSE/RESPIRATORY RATIO

Function	Condition	18-H Watch	24-H Schedule	18-H Watch	24-H Schedule
Body Temperature, °F	1 Week	98.29	98.39	0.23	0.21
		0.14	0.08	0.09	0.16
	2 Weeks	98.29	98.41	0.14	0.19
		0.06	0.21	0.08	0.14
	4 Weeks	98.38	98.51	0.11	0.15
		0.02	0.31	0.11	0.07
	6 Weeks	98.55	98.35	0.14	0.07
		0.10	0.37	0.07	0.32
	7 Weeks	98.45	98.44	0.14	0.18
		0.14	0.51	0.04	0.08
Pulse Rate	1 Week	67.81	68.91	6.36	3.76
		6.09	2.95	1.27	0.82
	2 Weeks	70.45	69.19	5.55	3.94
		6.92	5.03	1.11	0.70
	4 Weeks	69.36	69.63	4.19	5.61
		6.59	2.47	3.11	2.86
	6 Weeks	75.26	69.88	7.10	6.42
		7.79	5.98	7.10	5.31
	7 Weeks	71.3	68.96	3.09	9.45
		5.27	3.40	1.46	2.04
Respiratory Rate	1 Week	15.95	15.20	1.21	1.20
		0.50	1.60	0.46	0.56
	2 Weeks	16.03	14.44	1.08	1.34
		1.13	0.84	0.48	0.40
	4 Weeks	15.47	15.09	1.0	0.77
		1.38	0.55	0.35	0.56
	6 Weeks	15.63	14.82	1.18	1.43
		2.12	0.39	0.22	1.39
	7 Weeks	14.86	14.62	0.84	1.73
		3.20	1.05	0.44	0.22
Ratio Pulse Rate/Respiratory Rate	1 Week	4.35	4.65	0.34	0.33
		0.42	0.45	0.10	0.14
	2 Weeks	4.53	4.93	0.31	0.26
		0.67	0.65	0.10	0.07
	4 Weeks	4.61	4.71	0.24	0.26
		0.89	0.32	0.15	0.07
	6 Weeks	4.91	4.78	0.26	0.20
		0.89	0.48	0.29	0.06
	7 Weeks	5.01	4.79	0.22	0.16
		1.0	0.61	0.04	0.03

Values are means ± SEM (below mean); 24-h watch schedule, $n = 3$; 18-h watch schedule, $n = 3$.

TABLE 3
FREQUENCY DISTRIBUTION OF RHYTHMS DETECTED BY COSINOR ANALYSIS IN BODY TEMPERATURE, PULSE RATE, RESPIRATORY RATE, AND PULSE/RESPIRATION RATIO DURING PATROL

Rhythms, Range		Patrol									
Cycle Length, h		Week 1		Week 2		Week 4		Week 6		Week 7	
		18 H	24 H	18 H	24 H	18 H	24 H	18 H	24 H	18 H	24 H
48	(44–49)	8%	8%	14.5%	5.5%	–	22%	–	–	–	–
42	(40–43)	–	–	–	–	7%	–	17%	–	–	–
36	(29–39)	16%	46%	21%	42%	19%	–	–	–	30%	28%
24	(21–28)	46%	38%	29%	47%	43%	56%	33%	80%	30%	61%
18	(15–20)	15%	8%	21%	5.5%	31%	11%	33%	–	30%	5.5%
12	(10–14)	15%	–	14.5%	–	–	11%	17%	20%	10%	5.5%
Total		13	13	14	19	16	9	12	5	10	18

24-h watch schedule, n = 3; 18-h watch schedule, n = 3; 6 measurements daily.

Performance was not measured in these patrol studies. Levels of performance are known to be closely correlated with 24-h cycles of body temperature, showing peaks and troughs associated with the maxima and minima of body temperature (Colquohoun, Blake, and Edwards 1968; Voigt, Engel, and Klein 1968). As a result, one would expect that sub-cycles (12-h cycles) of body temperature, or cycles with 36- and 48-h periods, would alter the normal 24-h cyclic pattern of performance levels.

The trend toward a decrease in the mean amplitude of oral temperature of the group of five subjects (Table 1) after an 18-h watch (6 h on, 12 h off) is in agreement with findings obtained by Colquohoun et al. (1978), who reported body temperature changes in submarine personnel on a 4-h rotating watch-keeping cycle.

In the present study, however, additional physiological functions were measured. For example, respiratory rate also showed a reduction in amplitude during the patrol. Alterations that flatten the circadian rhythm in body temperature have also been observed in night-shift workers (Colquohoun et al. 1968; Folkard and Haines 1977).

TABLE 4
STATISTICALLY SIGNIFICANT 25–28 H CYCLES

Condition	No. of Significant 25–28 H Cycles
Pre-patrol Refit Period	0
Days 1–15	1
Days 41–52	5
Patrol	
1 Week	2
2 Weeks	2
4 Weeks	3
6 Weeks	1
7 Weeks	4

Isolation studies have shown that after elimination of all environmental time cues, the endogenous circadian cycles become "free running," generally exhibiting cycles of 25–28 h length (Schaefer et al. 1967; Aschoff 1969). Free running of cycles may also occur under conditions in which the environmental time givers produce mixed signals, which might disturb the organism's time structure. The fact that the number of 25–28 h cycles tended to increase with the duration of the patrols (Table 4) suggests that free running of cycles may indeed play a role during submarine patrols. The importance of these cyclic changes should be determined empirically in studies using continuous recording of physiological functions, such as body temperature, during selected segments of patrols. The average 3-day sleep periods for the first two weeks and the fourth week on patrol were 19.6 and 19.2 h, respectively, shorter than the 21.2 h reported by Colquohoun et al. (1978). A tendency toward a decrease in sleeping time to 17.2 h was also noted toward the end of the patrol. The significance of this finding also awaits further study.

The results of the analyses of the patrol data included in this study suggest that an 18-h watch schedule causes a disruption of circadian rhythms of physiological functions, a disruption resulting from the intrusion of higher and lower frequency cycles. The effects of such cyclic changes in the circadian system on health and performance have not been determined. These psychobiological questions require careful scientific investigation. For example, the question might arise whether other environmental factors, such as the increased CO_2 in the atmosphere, may have been responsible, at least in part, for the changes in circadian cycles. However, chronic exposure to 3% CO_2 and 2% CO_2 was not found to influence biorhythms (Carey, Schaefer, and Clegg 1966; Guillerm, Radziszewski, and Reinberg 1975).

From an observer's point of view, it would appear to be easy to change watch schedules that do not conform to a "physiological 24-h day" to a 24-h routine, as Kleitman suggested in 1949; however, there are operational constraints and personnel factors that have led to the present system of 18-h watch schedules. During the early Polaris patrols (early 1960s), the preferred work/rest cycle was 4 h on, 8 h off. This schedule was maintained because of its 24-h periodicity, which, presumably, caused minimum disruption of the 24-h day that the men were accustomed to under normal conditions. Two separate 4-h duty shifts were used. However, certain disadvantages became apparent when this regimen was used on prolonged patrols, in particular the occurrence of a sleep deficit. Since some "off-watch" time is spent on other activities, such as work on qualification programs, recreation, and so on, the actual time spent asleep was rarely more than 5–6 h. To alleviate this problem, the 6 h on, 12 h off schedule was introduced and is now being used on most submarines.

It is common for a certain percentage of the crew to have difficulty adjusting to the 18-h watch schedule, and the question has been raised whether this watch schedule contributes to a deterioration in the quality of sleep, performance decrements, and general malaise in those who cannot adjust to the 18-h schedule. Based on the results of the patrol studies presented in this paper and elsewhere, an hypothesis can be advanced: those who adjust optimally to the 18-h watch schedule may have rhythms with stronger 18-h frequency components, while those who have problems adapting to this schedule may persist rigidly in a 24-h cycle for many of their psychobiological functions.

If the 18-h watch schedule cannot be changed to a 24-h routine, it might be possible to facilitate personnel adjustment by shifting meal times from their present 24-h time schedule to an 18-h routine, thereby enforcing the effects of the 18-h watch schedule. Meal timing has been found to exert a powerful influence on cycles of hormones controlling metabolic functions, e.g., meal timing was found to shift the normal cyclic patterns of serum iron and insulin but not of plasma cortisol in human volunteers (Lakatua, Haus, Swoyer, Halberg, Thompson, and

Sackett 1975). It would not be too difficult to introduce 18-h meal timing and thereby eliminate the conflicting effects of two environmental time givers. Such measures might bring about an improvement in adjustment to the 18-h watch schedule. However, the ultimate aim should be to provide watch schedules that follow 24-h routines and therefore conform to the physiological day-night cycle.

Circumstances did not allow proper control studies of circadian cycles for sufficient periods before the refit period and patrols in both investigations, which has limited this report.

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Schaefer, K. E., C. M. Kerr, D. Buss, and E. Haus. 1979. Effets d'horaires de service de 18 heures sur les cycles circadiens de fonctions physiologiques pendant le service en sous-marin. 1979. Undersea Biomed. Res. Sub. Suppl.: S81–S90.—La température corporelle, la fréquence cardiaque, et la fréquence respiratoire ont été déterminées chez 11 sujets sous-mariniers tous les 4 heures pendant des périodes selectionnées du voyage. Les tensions artérielles systoliques et diastoliques ont été enrégistrées chez 5 sujets. Tous les sujets avaient un horaire de service de 18 heures (6 heures de travail suivies de 12 heures de repos) pendant la première série de déterminations. Pendant la deuxième série, 3 sujets avaient une horaire de 18 heures, tandis que 3 en avaient un de 24 heures. Nous nous sommes servis de tests de cosinor pour la détection positive ($P < 0{,}05$) du rhythme. Nous avons pu démontrer que chez tous les sujets qui avaient l'horaire de 18 heures, des cycles de la même durée se sont surimposés sur les cycles circadiens de la température corporelle, fréquences cardiaque et respiratoire, et tensions systolique et diastolique, dont les cycles de 24 heures continuaient aussi. Ces cycles de 18 heures ne sont pas observés chez les sujets dont les horaires de service étaient de 24 heures. En plus, nous avons observés des cycles de 12, 36, et 48 heures chez tous les sujets, ce qui met an évidence la dégradation des cycles circadiens sous ces conditions. La durée moyenne du sommeil est diminué vers la fin du service.

cycles circadiens
service en sous-marin
horaire de 18 heures
sommeil

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